NASA Technical Memorandum 83260

NASA LANGLEY RESEARCH CENTER TETHERED BALLOON SYSTEMS

Thomas L. Owens, Richard W. Storey, and Otto Youngbluth

FEBRUARY 1987

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

NASA Langley Research Center

TETHERED BALLOON SYSTEMS

Table of Contents

	Page
Introduction	1
Small Tethered Balloon System	2
Instrument Package	2
Ground Station	4
Electric Winch	5
Balloon	5
Large Tethered Balloon	5
Tether System	6
Separation System	7
Instrumentation Lab and Trailer	7
Flight Instrumentation Package	8
Data Retrieval System	9
Status	11

NASA Langley Research Center

TETHERED BALLOON SYSTEMS

INTRODUCTION

The Aerosol Research Branch (ARB) of the Atmospheric Sciences Division at the NASA Langley Research Center was involved in atmospheric research utilizing tethered balloon systems during the period of 1979 through 1983. Two separate tethered balloon systems were used which had payloads and configurations tailored to the needs and requirements of a given project. Each system was capable of measuring an atmospheric parameter or species in situ and then telemetering these data in real time to a ground station. Meteorological data and ozone concentration were typically measured with these systems. One system was capable of lifting 2.75 kilograms of payload to 800 meters. Four channels of data could be serially telemetered to the ground for real-time or post-experiment analysis. A larger balloon system was capable of lifting 45 kilograms to 775 meters or 30 kilograms to 2500 meters. The telemetry system had six channels of data acquisition capability which were stored for post-experiment analysis. Any four of the six channels could be displayed in real time.

The tethered balloons could be stationed at a required altitude or moved up and down at a rate ranging from 0 to 45 meters per minute. Additional information is available and will be provided upon request by Mr. Otto Youngbluth, NASA Langley Research Center, Mail Stop 475, Hampton, Virginia 23665.

SMALL TETHERED BALLOON SYSTEM

The small balloon system was used primarily to obtain meteorological and ozone data in the field. Some of the projects which this balloon system has supported are listed in Table I. This tethered balloon system (manufactured by Atmospheric Instrumentation Research Company of Boulder, Colorado) consisted of a blimp-shaped balloon, a flight sensor package, an electric winch with 800 meters of 50-kg test line, and a ground station with a modified HP-97 calculator. The entire system was portable and designed for two-man setup and operation (Figs. 1 and 2).

Profiles of the atmosphere from ground to 800 meters and return were accomplished in about 55 minutes. Five standard sensors were recorded on a single chart recorder in serial time-multiplex format. Full-scale synchronization and zero references were included in the recorded data to simplify real-time interpretation and insure data quality. All data were linear and scaled for quick chart interpretation.

Instrument Package

The instrument package (Fig. 3) contained sensors to detect barometric pressure, wind direction, wind speed, dry- and wet-bulb temperatures, and ozone concentration. The sensors were sequentially interrogated, and the data conditioned and transmitted to the ground station. Dry- and wet-bulb temperatures were sensed by precision-matched thermistors. A three-cup anemometer was used as the wind speed sensor and a clampable magnetic compass was used as the wind direction sensor. Pressure for deducing altitude was detected by a temperature-compensated aneroid transducer. The ozone sensor fit under the meteorology package. A tube extending through the bottom of the ozonesonde served as the inlet port through which air was drawn by a pump into a chamber.

A fresh solution of potassium iodide was poured into the chamber just prior to flight. The intake air, after passing through a filter to remove sulfur dioxide, was bubbled through the solution at a known rate so that oxidants in the air could react chemically with the potassium iodide. This reaction produced an electrical current between two electrodes immersed in the solution which was proportional to ozone concentration, the principal oxidant present in the Earth's boundary layer. An analog multiplexer interrogated each sensor voltage in time sequence. The signals modulated a voltage-controlled oscillator in the transmitter. The data were gathered and printed out every 26 seconds, the time required for a complete transmittal and data reduction cycle. One (selectable) sensor, however, could be sampled continuously.

The telemetry system consisted of an FM, crystal-controlled transmitter and receiver. Data were transmitted at 430 MHz in two formats on separate frequency multiplexed audio channels. One channel used an FM-FM PAM time multiplex format which could be recorded immediately on a single strip chart, an audio magnetic tape, or on both simultaneously. In this format, data quality was insured by including high and low reference data in the recordings. In the second format, data from any one sensor were transmitted continuously in FM-FM so that spectral information to 25 Hz was available. A block diagram illustrating the flight instrumentation package and the ground station is shown in Figure 4.

A data frame in the time multiplex format consisted of a wide synchronization pulse whose amplitude was full scale, followed by eight sensor channels separated by zero reference values. All sensor data are linear and are scaled in meteorological units for convenient chart interpretation.

The entire payload had been calibrated using standards which are traceable to NBS or are based on fundamental physical principles. No baseline reference calibration was required in the field. The measurement range and accuracy of the sensors are listed in Table II.

The flight instrument package contained an emergency termination system in the event the system lost its tether to ground. Termination would occur when the signal from the pressure sensor exceeded a preset level causing a pair of flash bulbs to be activated. The heat from the flash bulbs melts a small hole in the balloon, causing it to lose helium and descend.

Ground Station

The ground station was designed to process the instrument package data. The ground station contained a receiver, a microcomputer, a strip chart recorder, and a visual digital readout. All these components were contained in a metal carrying case. The case was also used to house the flight instrument package (Fig. 5). The ground receiver was a 400-420 MHz, narrow-band, crystal controlled FM receiver (nominal frequency is 403 MHz). The microcomputer contained an Intel 8080A microprocessor and 2500 words of memory. Most of the memory was ROM (read only memory); therefore, the program in the computer was permanent and could not be changed without replacing the ROM.

One output device was the built-in chart recorder. It could accept output from any data channel which was selected using a toggle switch. Another output was the MET DATA display which is made up of light-emitting diodes. The measurement being displayed was indicated by a series of labeled lights below the displayed number. There were output connectors for a printer and an audio cassette recorder. The printer output was connected to a modified HP-97 (Hewlett Packard) printer calculator which automatically printed the output display by MET DATA display.

Electric Winch

The electric winch (Fig. 6) was powered by a 12-volt d.c. permanent magnet motor. The winch speed and direction were controlled by varying the armature voltage and polarity from 0 V to ±12 V. The ascent and descent rates were 0 to 30 meters per minute. A Kevlar braided 900-meter tether line, 0.64-mm in diameter, weighing 40 grams per 100 meters and having a break strength of 50 kilograms, was used as the tether line.

Balloon

The blimp-shaped balloon was made of urethane-coated nylon fabric with four inflatable fins. During extended periods of operation, it was kept in a shelter between flights and occasionally "topped off" with helium to maintain proper inflation. The balloon had four attachment points; the two forward points were used to attach the tether line, while the two aft points were used to attach the sensor package (Fig. 1).

The system had aerodynamic lift; consequently, the wind contributed to raising the system to its desired height. The balloon had an operating altitude limit of about 800 meters. The balloon would fly safely in winds up to 10 meters/sec. At higher wind speeds, the balloon system would exhibit unstable flight.

LARGE TETHERED BALLOON

Two large tethered balloon sizes were available for use, depending on the payload, altitude, and weight requirements. Both balloons (models TRF2D-3500 and TRF3D-3500) were manufactured by Raven Industries, Inc. The difference between the two balloons is the number of dilation panels. Some of the projects which this balloon system has supported are listed in Table III.

The balloons are aerodynamically shaped non-rigid structures conforming to a modified class "C" shape with a fineness ratio of 2.75 to 1. These balloons are stable in winds up to 28 meters/sec. The hulls are made from urethane coated nylon fabric and have a rigid 4-fin tail assembly (Fig. 7). The fin framework consists of aluminum tubing to which the fin fabric is laced. Load lines are attached to the hull and converge to a single point below the balloon for attachment to the tether line. The balloons have a dilation panel to compensate for internal pressure changes resulting from temperature and altitude variations. The tether line is made of braided Kevlar with a nylon-braided scuff jacket. The line is 3.18-mm diameter, weighs 7.4 kg per 1000 m, has a breaking strength of 725 kilograms, and is 3100 meters long.

Tether System

The tether system was powered by a 5 horsepower motor coupled to a gear box (Fig. 8). The motor had a self-cooling blower and a fail-safe magnetic brake. An SCR (Silicon Controlled Rectifier) controller provided variable speed control, with forward and reverse speeds as well as a stop position. The motor gear box provided 7.25 kilogram-meters of torque over the range of 4 to 87 RPM.

The gear box used a chain drive to rotate the retrieval drum on which the Kevlar tether line was wound. There was also a level wind mechanism to uniformly wind the line on the drum. The line exited through the level wind to a fair lead pulley located about 30 meters in front of the trailer (Fig. 9). The fair lead pulley was attached to a large plate which was secured to the ground by 180 kg. of lead weights. This pulley permitted the balloon to be launched and retrieved in an unobstructed area.

Separation System

The payload separation system was a radio command system consisting of a receiver/decoder and transmitter/encoder. The receiver package of approximately 0.19 kg was packaged in a weather resistant case and was mounted on the underside of the payload. Nickel-cadmium batteries provided a 48-hour operational period before recharging was required. The flight payload 12-volt power supply was used to fire the line-cutting devices to separate the payload from the balloon. The transmitter/encoder was configured to operate at a frequency of 164 MHz. The transmitter operated at 7 watts in the VHF band and 4 watts in the UHF band. The tranmitter/encoder transmitted a coded signal for commanding the receiver/decoder to electrically activate two line cutters.

A 3.66-m diameter flat circular parachute was used for payload recovery. The parachute was packaged in a fabric deployment bag which was attached to the payload suspension bar. The parachute risers were then connected to the payload. On command, the line cutters severed the lines connecting the payload package to the payload suspension bar, causing the parachute to extract and deploy as it descended.

Instrumentation Lab and Trailer

A flatbed trailer (Fig. 10) was used as a base for the ground support equipment, the launch and retrieval equipment, and the ground station and data-gathering equipment. The tether drive and control system were located on the front end of the flatbed. The receiver antenna was also located toward the front of the trailer adjacent to the winch. The lab contained all the ground station and data processing equipment. The lab had both air conditioning and heating, and operated from a 220 volt, 3 phase line. The trailer could be routinely moved overland to field sites by a standard tractor.

Flight Instrumentation Package

The flight instrumentation package was fabricated from aluminum and is illustrated in Figures 11, 12, and 13. It was 0.41-meter long, 0.41-meter high, and 0.41-meter wide (0.68-cubic meter) and was supported on four legs and a base. During flight the package was suspended 15 meters below the balloon. The flight package weight was approximately 20 kilograms. It was divided into two sections. The top section contained the basic meteorological data-gathering sensors and associated electronics. The bottom section was available for specific experimental equipment such as aerosol and ozone instruments.

The basic meteorological data-gathering sensors were the wind speed anemometer, altitude transducer, dry- and wet-bulb thinistors, and wind direction indicator. The specifications for these sensors are delineated in Table IV.

The Quartz Crystal Microbalance (QCM) Impactor was a 10-stage aerodynamic inertial impactor used for collecting and measuring the mass concentration and size distribution of suspended aerosol particles. The principal feature of the QCM was its ability to separate submicrometer particles down to 0.05-micrometer diameter and provide size distribution and mass concentration data.

The ozone sampler was an electrochemical concentration cell ozonesonde used for measuring the vertical distribution of atmospheric ozone. The sensor used within the sonde was an iodine-iodide redox electrode concentration cell made of two bright platinum electrodes immersed in potassium iodide solutions of different concentrations contained in separate cathode and anode chambers that are fabricated from Teflon resin. The chambers were linked together with an ion bridge which served as an ion pathway and retarded mixing of the cathode and anode electrolytes, thereby preserving their concentrations.

An air pump bubbled air containing ozone through the cathode electrolyte, resulting in the release of iodide and an electrical current proportional to the ozone concentration. The current (0-6 ma) emitted by the electrochemical concentration cell during the measurement of ozone was impressed upon a simple two-transistor coupler, the resistance of which varied with the magnitude of the impressed current.

Data Retrieval System

The output from each sensor in the flight instrument package was converted to a frequency and was coded by frequency-shift keying. All the signals were summed and the resultant signal modulated the 1680 megahertz transmitter. The data were telemetered continuously to the ground receiver (Fig. 14).

The receiver stripped the 1680 MHz signal, and the information signal was recorded on channel 1 of a 2-channel audio tape recorder. A real-time clock was recorded on channel 2. The information signal was also applied to a 10-channel Frequency Shift Key (FSK) demodulator. This unit separated the information signal into the original six FSK channels and demodulated these signals to a form in which frequency was proportional to the measured parameter. These signals were converted from frequency to digital information by an interface unit. The output of the interface was applied to the Tektronix 4051 over a general purpose interface bus. The 4051 accepted two complete sets of data at a 1-second interval. A computing process took place which allowed three selected parameters to be plotted against altitude on the graphics display (Fig. 15) while all the computed data were recorded on a cassette tape. This process was repeated every 5 seconds until the 4051 memory was filled, representing a matrix of 250 by 7 channels. In the field, a hard copy of the data plots could be obtained along with the listing of a 250- by 5-channel memory matrix.

Status

The tethered balloon systems have a distinct advantage over other methods of tropospheric environmental data gathering. In the region of 0 to 3 kilometers above the Earth's surface, most conventional in situ air sampling techniques have serious drawbacks. Ground-based observations cannot provide the vertical or horizontal variability, and aircraft-based observations have sampling problems caused by lack of instrument response and difficulties in understanding probe losses. It is also difficult for aircraft to develop unintrusive vertical profiles. Instrumented tethered balloon systems, however, do not suffer from these limitations for tropospheric and boundary layer measurements. Furthermore, the system's real time capability enables the researcher to make decisions in the field during experiments. The FM sideband configuration also allows simultaneous multiple parameter measurements.

Several reports have been written in reference to studies which were performed using the balloon systems as research instruments. Some of these reports are:

1. Youngbluth, O. Jr.; Storey, R. W.; Clendenin, C. G.; Jones, S.; and Leighty, B.: "Ozone Profiles From Tethered Balloon Measurements In An Urban Plume Experiment." IEEE Southeastern Convention, Huntsville, Alabama, April 5-8, 1981.

2. Holzworth, R. H.; Dozey, M. H.; Schnauss, E. R. and Youngbluth, O. Jr.: "Direct Measurement Of Lower Atmospheric Vertical Potential Differences." Report No. SSL-81(7881)-03. The Aerospace Corporation, Los Angeles, California, 1981.

3. Sentell, R. J.; Storey, R. W.; Chang, J. J. C. and Jacobson, S. J.: "Tethered Balloon-Based Measurements of Meteorological Variables and Aerosols." NASA TMX-73999 (NTIS N77-15586), December 1976.

TABLE I.- Small Balloon System Past Projects

Project	Date	Location	Data Gathered
Southeastern Virginia Urban Plume Study	July-Aug. 1979	Chesapeake, VA	Meteorology and Ozone
Flight Effects Project (OVIB)*	October 1979	Wallops Flight Center, VA	Meteorology
Excess Ground Attenuation Tower Test	November 1979	Wallops Flight Center, VA	Meteorology
PEPE/NEROS**	July-Aug. 1980	Columbus, OH	Meteorology and Ozone
Flight Effects Project (OVIB)	September 1980 June 1981 November 1981	Wallops Flight Center, VA	Meteorology
Summer Experiment	July-Aug. 1981	Fort Story, VA	Meteorology and Ozone

*Flight effects on fan noise program utilizing OVIB aircraft with JT15D test engine.

**Persistent Elevated Pollution Episodes/Northeast Region Oxidant Studies

TABLE II.- Small Balloon System Specifications

A. Flight Package Sensors

Dry- and wet-bulb temperature	-50° to +50° C ±0.5° C
Pressure	0 to 100 millibars ±1 mb
Wind speed	0.5 to 20 m/s ±0.25 m/s
Wind direction	0-360° ±5°
Ozonesonde	ppb ± 10%

B. Telemetry Link

Modulation	PAM-FM (time multiplex)
Frequency	3 kHz ±7.5%
Format	Time multiplex on channel A; continuous on B

C. Transmitter

Frequency	400-420 MHz FM
Frequency stability	(-30 to +60° C) 0.0005%
Modulation	16 F3
Power output	5 mW

D. Flight Package

Size	9 by 12 by 48 cm
Weight (without ozonesonde)	1.0 kg
Weight (with ozondesonde)	1.22 kg
Maximum altitude	800 meters

E. Ground Receiver

Frequency range	400-420 MHz FM
Number of channels	4
Frequency stability	(0° to +60° C) 0.0005%
Channel spacing	25 kHz
Sensitivity	0.5 ^{e}v
Selectivity	60 db
Audio output	500 mW
Size	15 by 11.5 by 44.5 cm
Weight	672 g
Antenna	15-cm whip with ground plain
Microcomputer	Intel 8080A with 2500 word memory

TABLE II. (continued)

F. Balloon

Size	4.9 x 1.39 m
Volume	4.25 m^3
Static lift (sea level)	4.0 kg
Material	Urethane coated nylon fabric
Helium required	Approx. 1-K cylinder

G. Winch

Line	0.64-mm dia KEVLAR, 50-kg B.S., 915 meters 0.40 kg/km
Weight	27 kg (59.5 lb)
Size	40 by 23 by 25 cm (15.75 by 9.06 by 9.84 in.)
Power	12 V @ 1-5A

TABLE III.- Large Balloon System Past Projects

Project	Date	Location	Data Gathered
Southeastern Virginia Urban Plume Study	July-Aug. 1979	Wallops Island, Virginia	Ozone, Meteorology
PEPE/NEROS*	July-Aug. 1980	Aberdeen Providing Ground, Maryland	Ozone, Meteorology
Properties of Atm. Particles in Arid Regions	March 1980	Tucson, Arizona	Aerosols, Meteorology
Hi-Wire	Sept. 1980 May 1981	Wallops Island, Virginia	Meteorology
Wide Body Noise Effects	Nov. 1980	Wallops Flight Center, Virginia	Meteorology
Trash Burner Pollution Study	Dec. 1980	Langley Research Center, Virginia	Meteorology Aerosols
Summer Experiment	July-Aug. 1981	Northwest, Virginia	Ozone Meteorology
Trace Gas Sampling	Sept. 1983	Wallops Island, Virginia	Salt Water Marsh Gases

*Persistent Elevated Pollution Episodes/Northeast Region Oxidant Studies

TABLE IV.- Large System Flight Instruments Specifications

Wind Speed Anemometer

Make: Weather Measures
Model: W-103
Calibration: Wyle Labs. 0-28 m/sec.
Precision 0.2m/sec.
Threshold 0.6 mph
Accuracy ±1%

Altitude Transducer

Make: Paroscientific Corp. - Digiquartz
Model: 230A-002
Callibration: Wyle Labs.
Meas. Acc: ±10.5 m repeatability 0.005% FS

Dry- and Wet-Bulb Thermistors

Make: Victory Eng. Col
Model: Thinistor 41 K-2A-200
Meas. Acc: ±0.05° F; 5-10% rel humidity
Time Constant: 3-5 sec dry
30-60 sec wet

Wind Direction Indicator

Make: Supplier A.I.R.
Mode: Tethersonde
Calibration: Precision ±5°; resolution 1°
Time Constant: 2-5 sec

Ozone Sampler

Make: Science Pump Corp.
Model: Electrochemical Concentration Cell
Accuracy: ±5% of calibration with no interference
Time Constant: 30-70 sec

Sizing Aerosol Counter

Make: California Measurements, Inc.
Model: PC-2, cascade impactor
Type: Quartz Crystal Unbalance
Time Constant: Approx. 90 sec
Stages: 9

NASA
L-80-7196

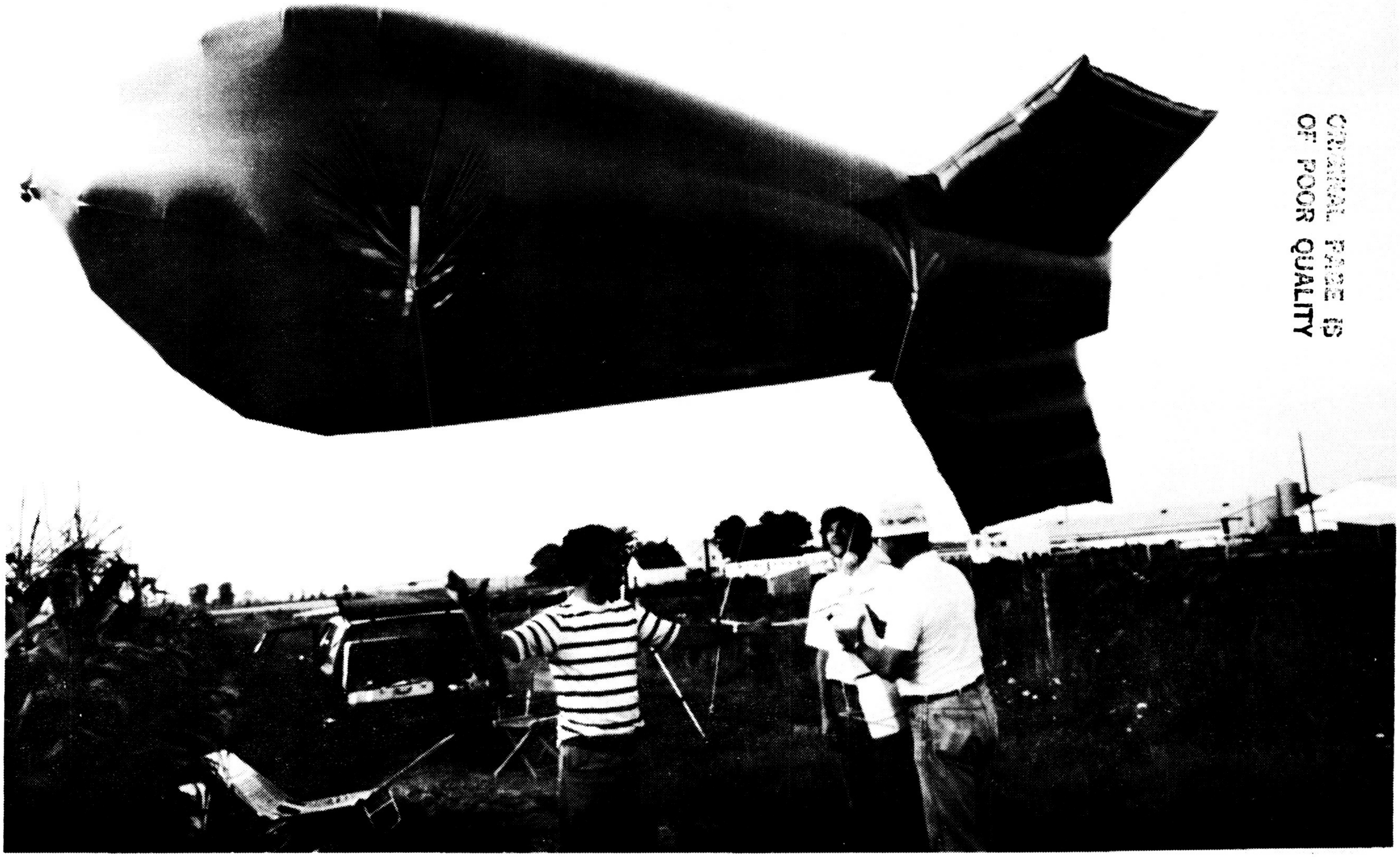

Figure 1. Small Balloon and Flight Instrumentation Package

Figure 2. Data Gathering & Ground Support Equipment

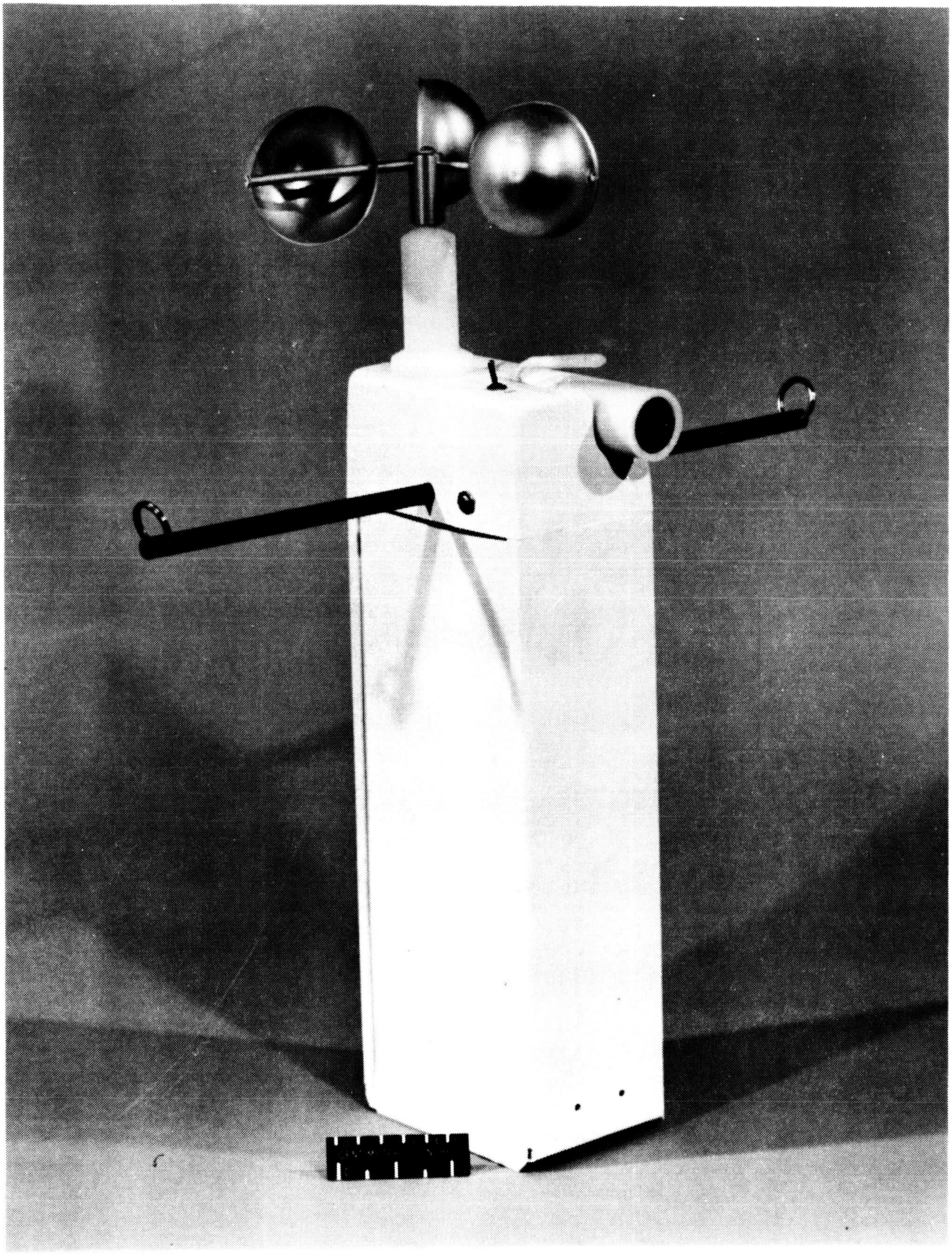

Figure 3. Flight Instrument Package

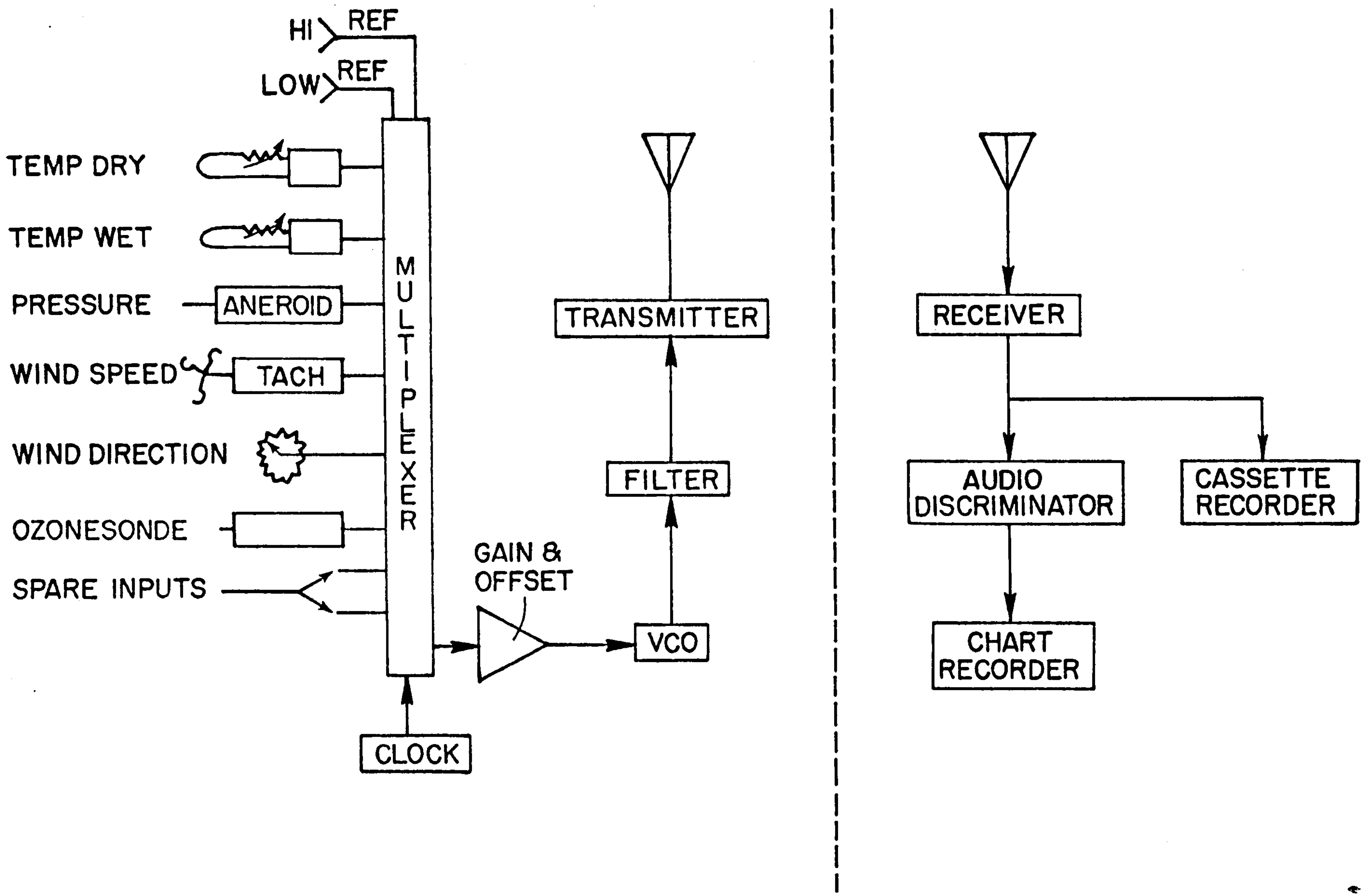

Figure 4. Block Diagram Of System Electronics

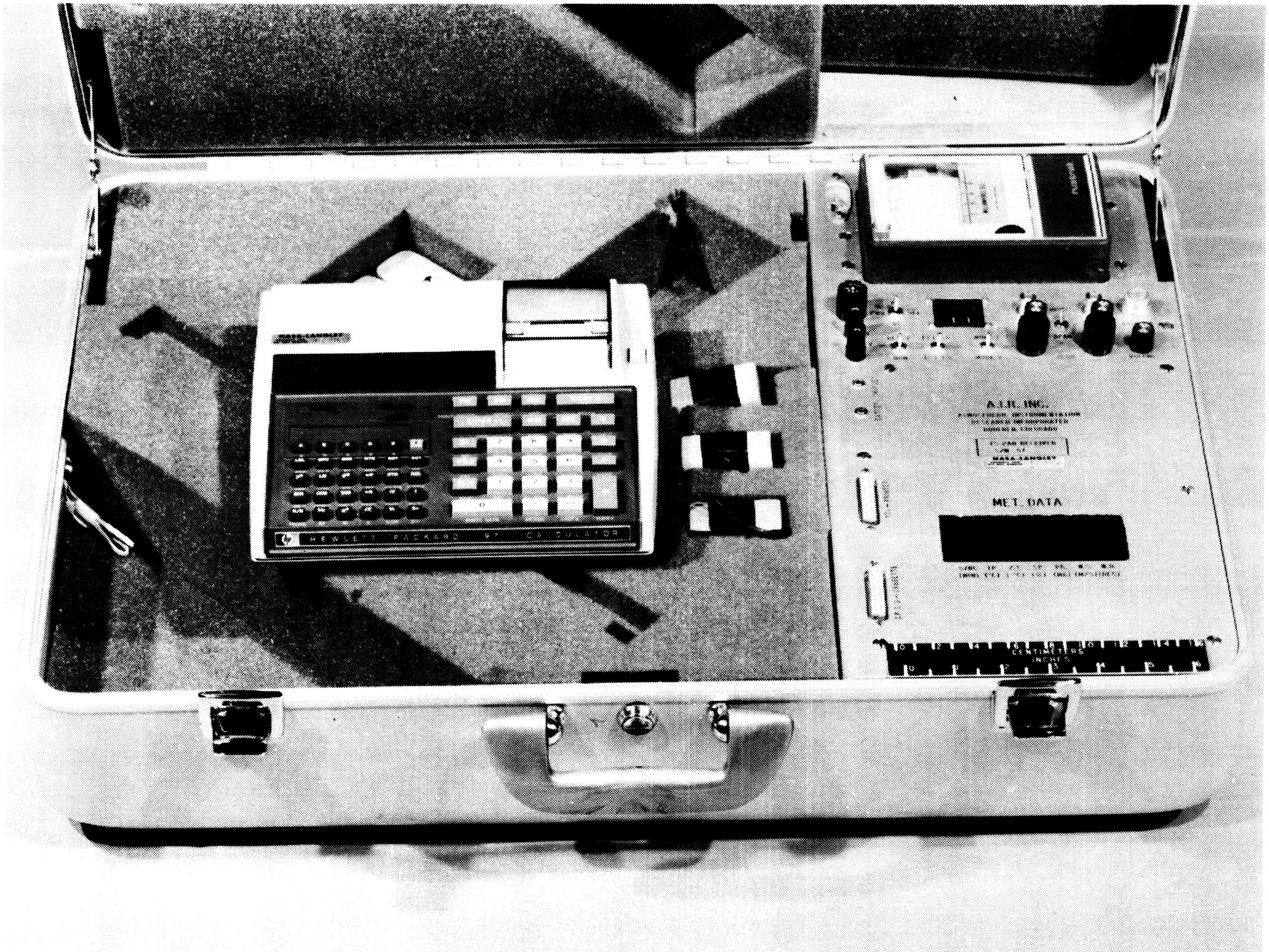

Figure 5. Ground Station

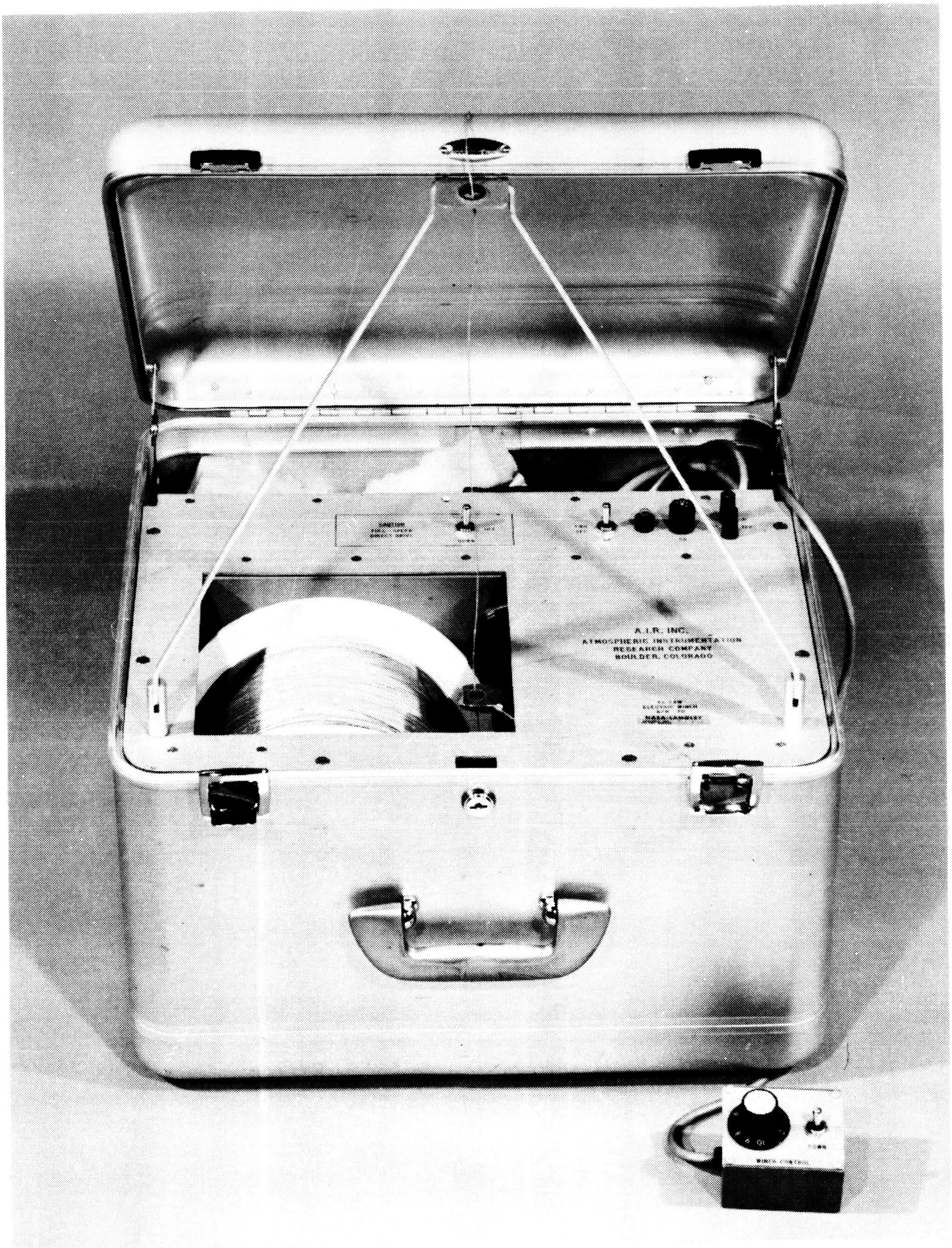

Figure 6. Electric Winch

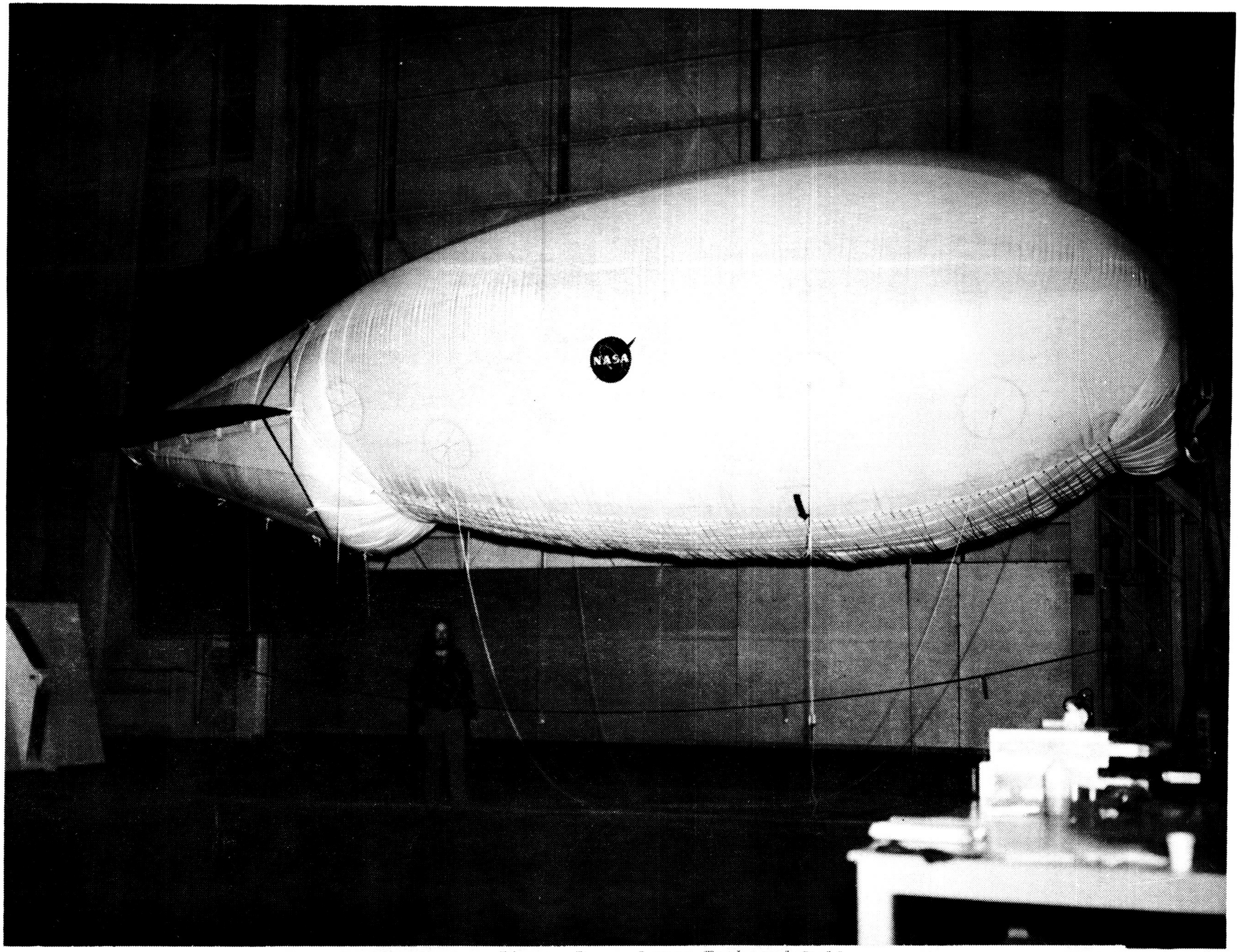

Figure 7. Large Tethered Balloon

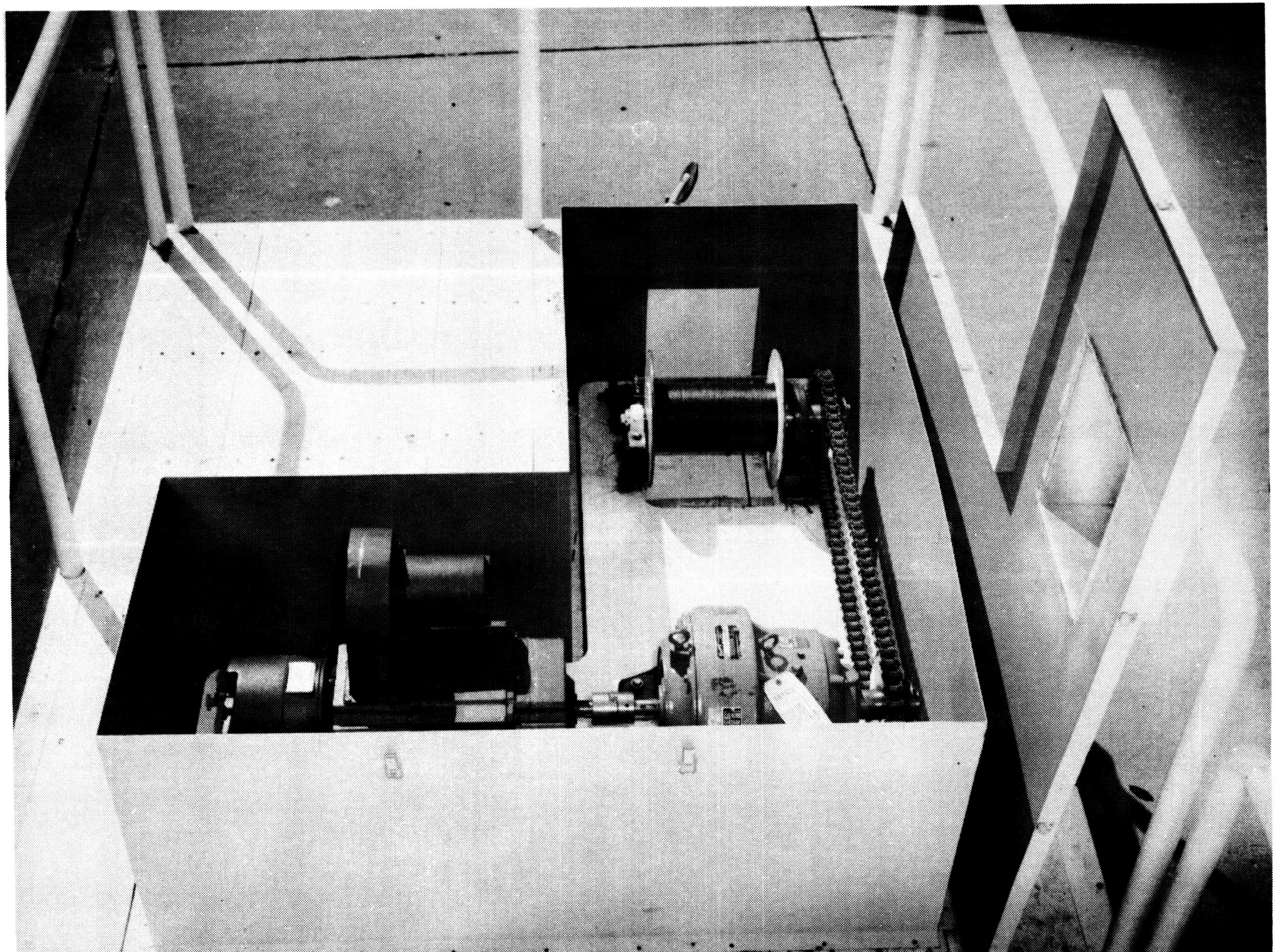

Figure 8. Tether Drive System

Figure 9. Fair Lead Pulley & Anchor Plate

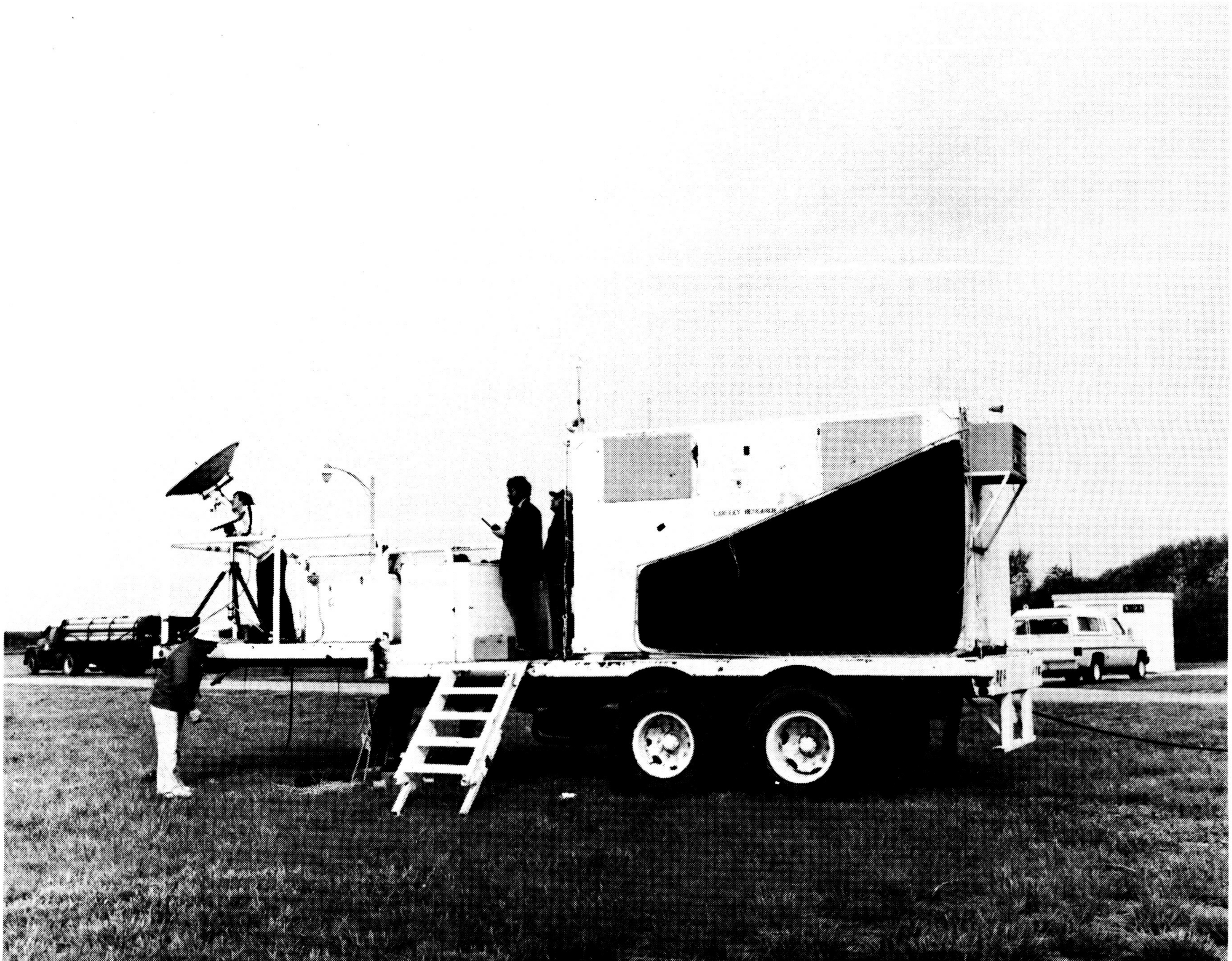

Figure 10. Instrumentation Lab & Trailer

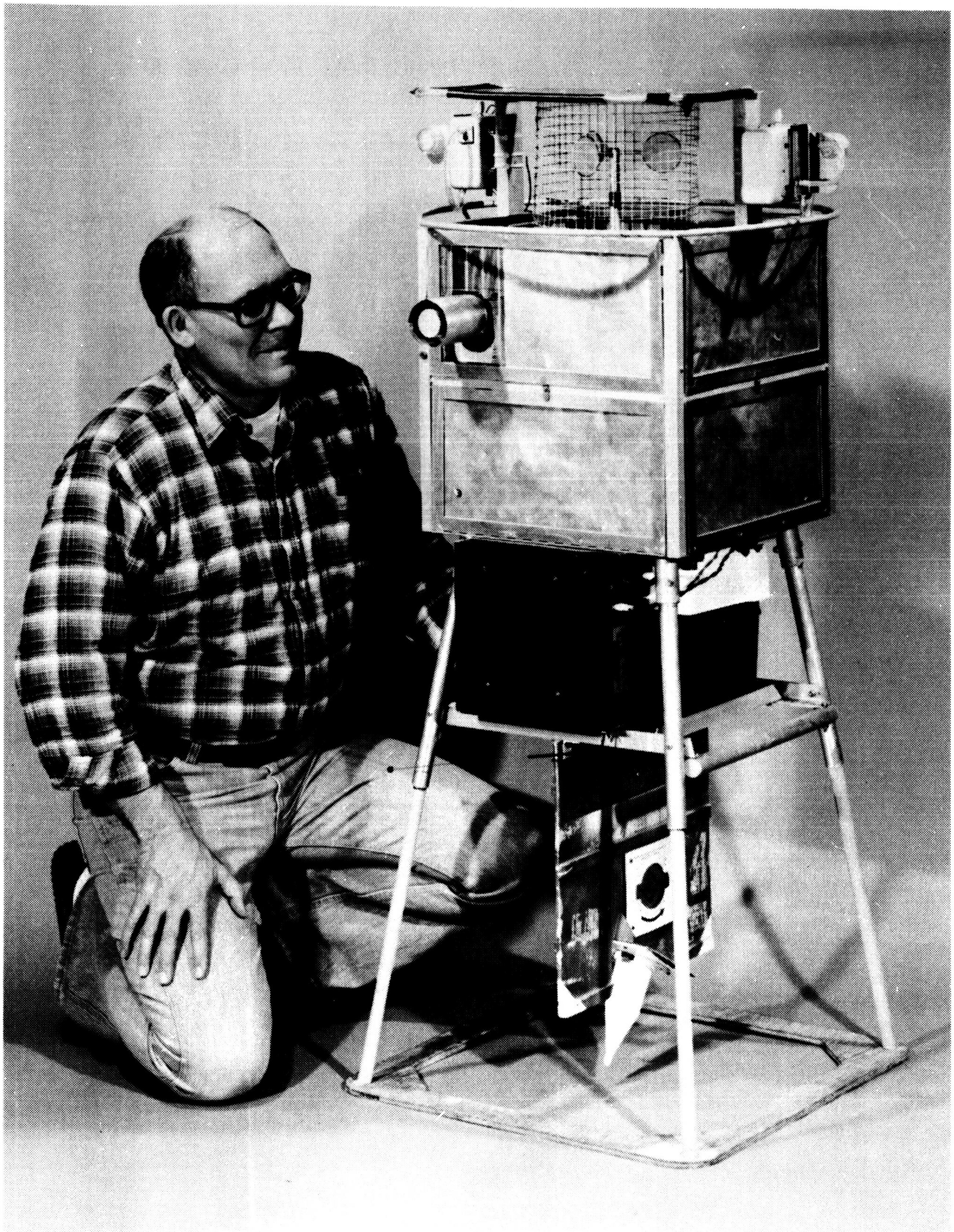

Figure 11. Flight Instrument Package

Figure 12. Side View, Flight Instrument Package

ORIGINAL PAGE IS
OF POOR QUALITY

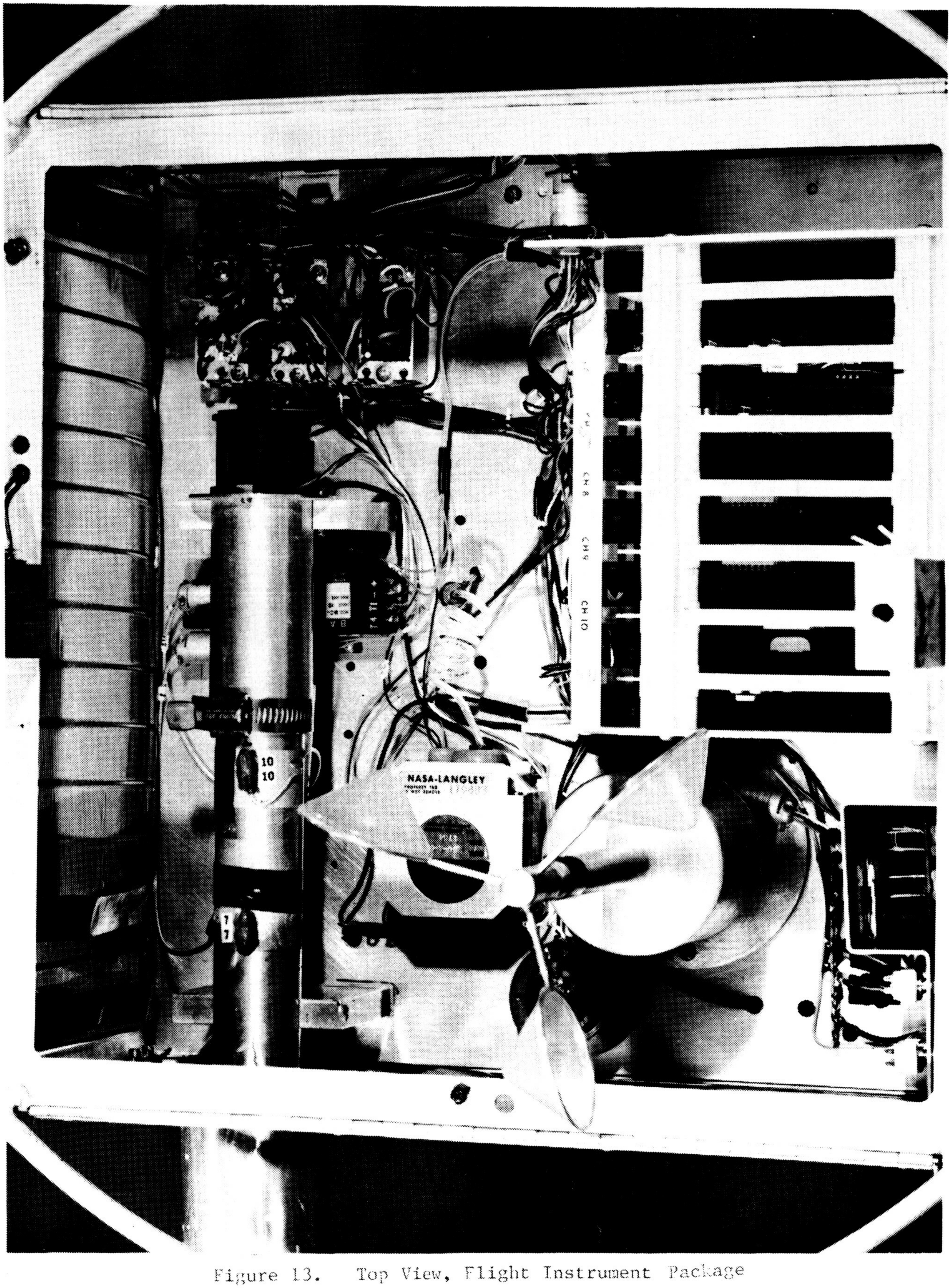

Figure 13. Top View, Flight Instrument Package

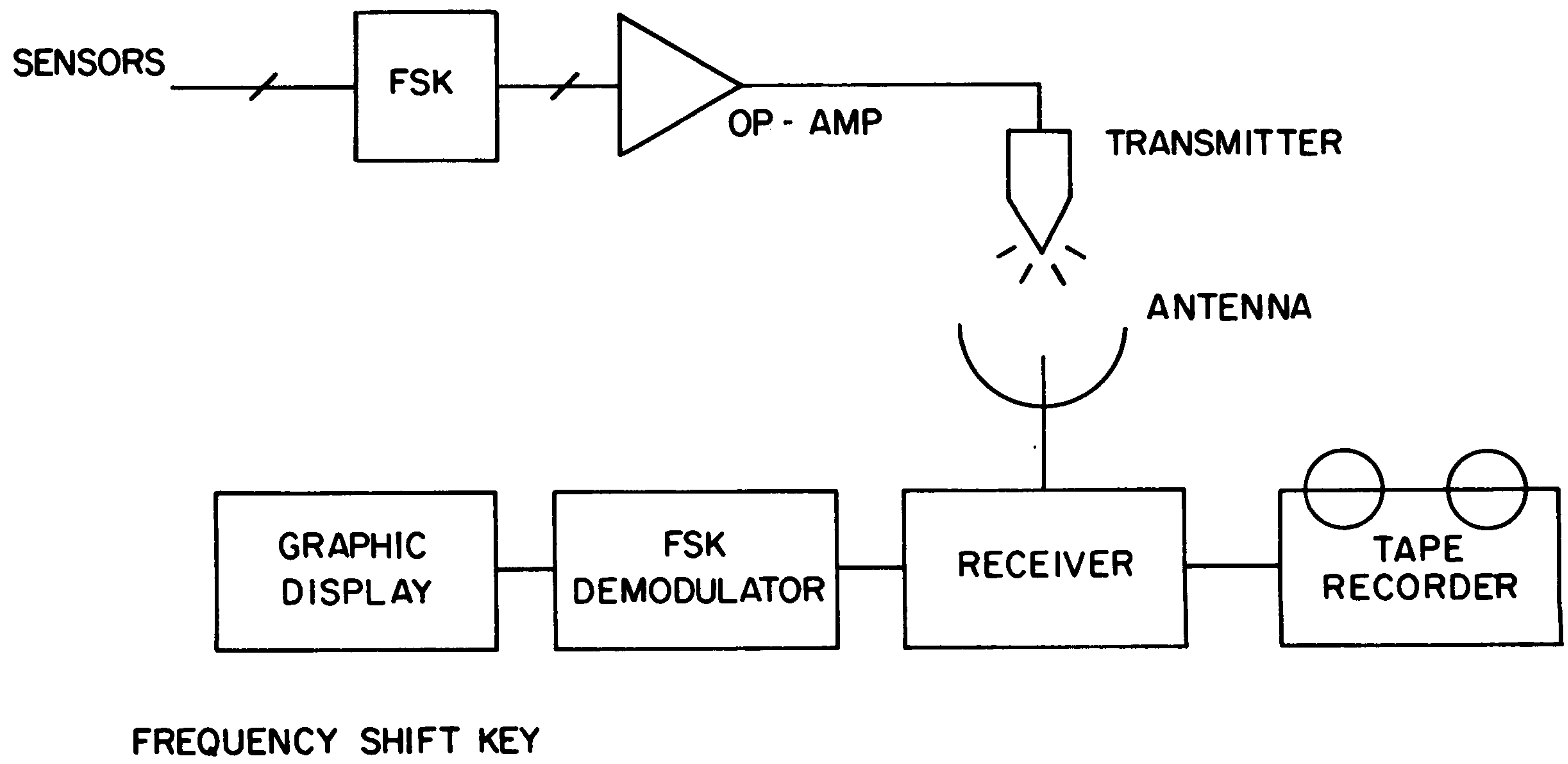

Figure 14. Large Tethered Balloon Instrumentation

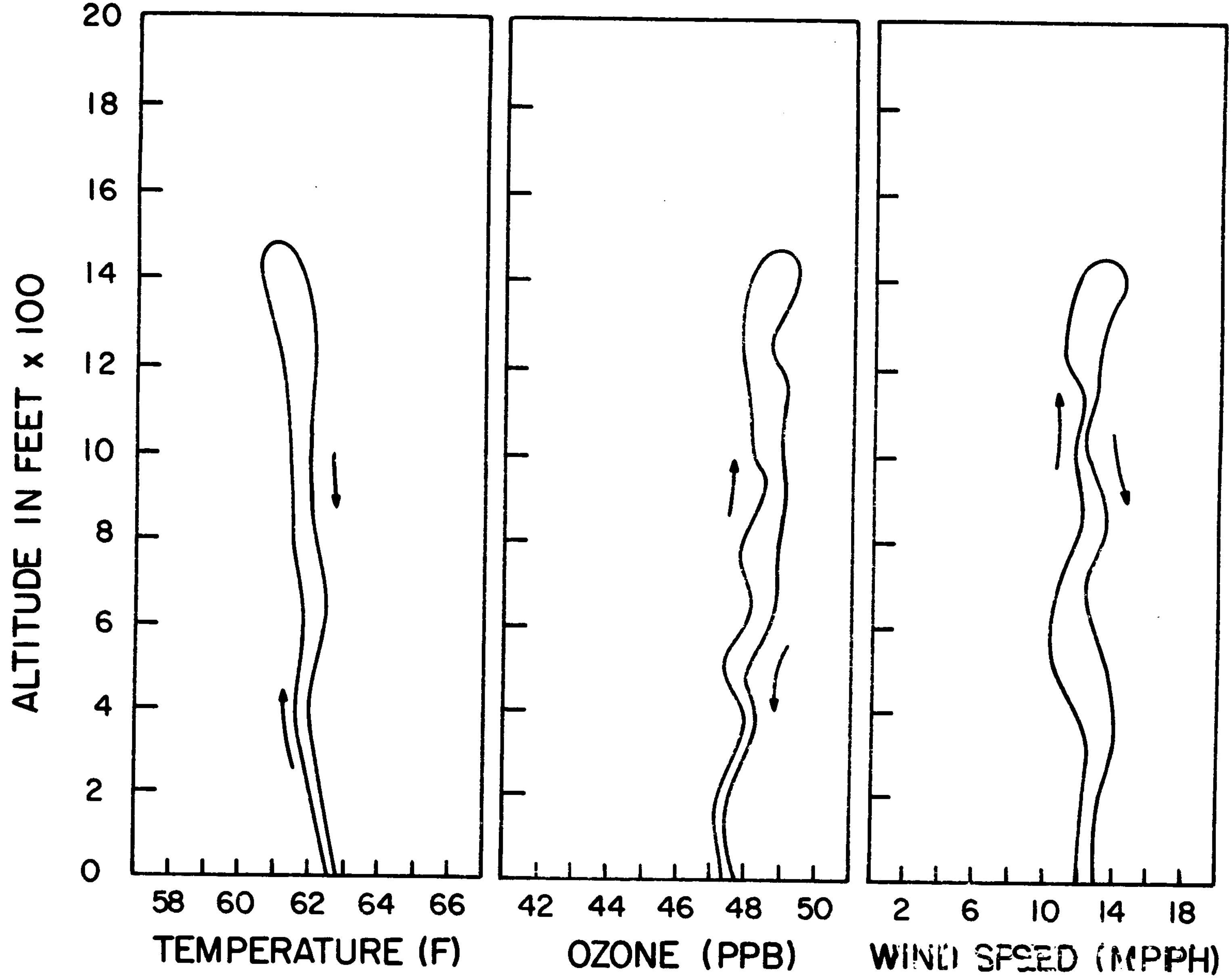

Figure 15. Typical Temperature, Ozone, Wind Speed, Altitude Profile.

Standard Bibliographic Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-83260		
4. Title and Subtitle NASA Langley Research Center Tethered Balloon Systems		5. Report Date February 1987
		6. Performing Organization Code 665-45-20
7. Author(s) Thomas L. Owens, Richard W. Storey, and Otto Youngbluth		8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The NASA Langley Research Center tethered balloon system operatins are covered in this report for the period of 1979 through 1983. Meteorological data, ozone concentrations, and other data were obtained from in situ measurements. The large tethered balloon had a lifting capability of 30 kilograms to 2500 meters. The report includes descriptions of the various components of the balloon systems such as the balloons, the sensors, the electronics, and the hardware. Several photographs of the system are included as well as a list of projects including the types of data gathered.

17. Key Words (Suggested by Authors(s))	18. Distribution Statement
Tethered Balloons Atmospheric measurements Boundary Layer In situ sampling	Unclassified-Unlimited Subject Category 46

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	33	A03

For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA Langley Form 63 (June 1985)